IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of	:	Robert G. Wilhelm, et al.
Application No.	:	09/876,915
For	:	**SYSTEMS AND METHODS FOR ADAPTIVE SAMPLING AND ESTIMATING A SYSTEMATIC RELATIONSHIP BETWEEN A PLURALITY OF POINTS**
Filed	:	6/08/2001
Examiner	:	G.M. Desire
Art Unit	:	2624

Mail Stop **Amendment**
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

AMENDMENT AND RESPONSE TO NON-FINAL OFFICE ACTION

Sir:

The following Amendment and Remarks are submitted in response to the Office Action mailed July 2, 2004.

Amendments to the Specification begin on page 2 of this paper.

Amendments to the Claims begin on page 6 of this paper.

Remarks begin on page 13 of this paper.

AMENDMENTS TO THE SPECIFICATION

Pease replace the identified paragraphs in the specification with the following:

[0004] Further, for example, the points identified by the sampling plan will dramatically affect the accuracy of the estimation. Many sampling plans include a grid-like array of points having a given spaced-apart relationship. For example, such a grid-like array may be obtained in a "line scan". In order to obtain an accurate estimation of the form, however, a sampling plan may need to include denser grids in some portions of the form, such as in portions of the form having complex shapes. Also, for example, a grid-like sampling plan having predetermined spacing may waste time making measurement in portions of the form that are uncomplicated and thus may be estimated with only a few samples. Additionally, having a sample plan that samples a lot of points in a non-complex portion of the form may increase the variability of the estimate. As such, the development of a<u>n</u> accurate sampling plan for a given form may require a high investment in time and cost. Also, the time and cost is further multiplied for every form for which an estimate is required. Thus, the accuracy and completeness of the form estimation, as well as the time required to perform the measurements, is highly dependent on the sampling plan.

[0010] In another embodiment, a method for estimating a relationship between a plurality of points, comprises: generating a first estimated relationship between the plurality of points based on measured coordinate data and normal vector data, the measured coordinate data comprising a measured value of a vector associated with a point corresponding to a given one of the plurality of points, the normal vector data representative of a local rate of change with respect to the vector associated with the given one of the plurality of points, the first estimated relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; [a]and automatically determining whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria.

[0013] In a further embodiment, a computer readable medium for estimating a systematic relationship between a plurality of points, comprises: an estimation module having a predetermined estimation function operative to generate a first estimated systematic relationship between the plurality of points based on coordinate data and normal vector data, the coordinate data comprising a measured value of a vector corresponding to a given one of the plurality of points, ~~the ,~~the first estimated systematic relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; and an adaptive sampling module operative to automatically determine whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria.

[0022] Referring to Fig. 1, in one embodiment, a form estimation system 10 for estimating a shape of a form 12 defined by a plurality of points 14 includes an estimator 16 that receives measured or computed position data 18 and measured or computed normal vector data 20 associated with given points on the form and generates an estimated shape 22 based thereon and according to an estimation function 24. Estimation function 24 processes position data 18~~position data 18~~ and normal vector data 20, or data error 30 associated therewith, according to a predetermined mathematical model to predict a shape of form 12 based on values associated with the measured or computed points. A measurement device 26 may supply position data 18 and normal vector data 20 to estimator 16. Additionally, estimator 16 may include an adaptive sampling mechanism 28 that determines error 30 associated with the data, determines whether further measurements are required depending on the magnitude of the error, and identifies at least one target point 32 on form 12 for further measurement. Adaptive sampling mechanism 28 is driven by, among other factors, the normal vector data 20, error 30 and a predetermined error limit 34 to automatically make the sampling decision. Further, estimator 16 may include a data verification device 36 for analyzing the measured/computed data or error data with respect to estimated data in order to verify the accuracy of the measured/computed data or error data and remove inaccurate data. Thus,

form estimation system 10 utilizes position data and normal vector data to automatically sample points on form 12 according to adaptive sampling mechanism 28 and to predict the shape of the form 12 according to estimator 16 such that the estimated shape 22 is accurate within predetermined error limit 34.

[0023] Form 12 includes a surface, a waveform, any object, or any physical or artificially-generated phenomenon having a measurable shape or having a systematic relationship between points. Plurality of points 14 includes points that define the surface of form 12. Each of the plurality of points 14 includes associated data that describe the point, including actual position data 38 and actual normal vector data 40. As used herein, the term "position data" includes any coordinate data that can be represented in vector space, such as, in one example, the position of the point in an x-, y- and z-axis coordinate system. The term "normal vector data" includes data representing the magnitude and direction of a vector positioned normal to a line or plane tangentially positioned with respect to a given point on the form, or data that describes or estimates the instantaneous rate of change of the position data. For example, form 12 may be an object that system 10 measures and compares against a desired nominal shape, or the form may have an unknown shape requiring definition by the system.

[0028] Measurement device 26 measures the value of position data and measures or estimates normal vector data at a given point on form 12. Measurement device 26 may include, for example, a coordinate measurement machine (CMM), an oscilloscope, an electronic measurement device, a laser measurement device, an optical measurement device, a mechanical measurement device; devices that measure color, sound, motion, position, temperature, velocity, acceleration and other physical characteristics via mechanical, electrical, electronic, optical, hydraulic sensors; devices that measure simulated signals generated via computer simulation or from data stored in a data base., or any other device capable of measuring and/or estimating the value of position and normal vector data.

[0032] Referring to Fig. 2, one embodiment of a method for estimating the shape of a form having a plurality of points includes identifying a starting set of points on the form for measurement (Block 70). The starting set of points ~~are~~ is evaluated to determine whether or not they meet the predetermined sample spacing limits (Block 72). If the starting set does not meet the limits, such as if the points are too closely spaced or spaced too far apart, then a new starting set of points is generated that meet the spacing limits (Block 74). If the starting set does meet the limits, then the next action may be taken (see Block 76, described below). In one embodiment, the starting set of points defines a boundary of the form, and the starting set comprises at least three non-linear points. As such, the form is covered by a "triangular patch" defined by the three points. In one embodiment, one or more triangular patches are identified to cover the portion of the form of interest, where adjacent triangular patches may share all or a portion of a side of a triangular patch. Once one triangular patch is evaluated using the described methodology, the system moves on to the remaining triangular patches until the entire portion of interest of the form has been evaluated. It should be noted that any number of points may be utilized, from a single point to a plurality of points, with the number of points varying depending on the estimation function utilized. Further, it should be noted that rectangular, square, or any other shaped patches may also be utilized. The method works the same for any type of patch -- the boundaries could be curves, discrete point sets, or any rule sets that describe which points are on the surface and which are not. Further, surface models that have boundaries outside of the zone formed by the sample points may also be used. Alternatively, the starting set of points may comprise a single line, or two or more lines of spaced-apart points, for example a grid-like array of spaced-apart points, such as may typically be utilized in a line scan type of sampling plan. In one embodiment utilizing such a spaced-apart starting set, the triangular patches are chosen from among the plurality of spaced-apart points such that the three points are not co-linear. In such a manner, a portion of a surface perpendicular to an initial line scan may be evaluated.

AMENDMENTS TO THE CLAIMS

1. (currently amended) A method for estimating a systematic relationship between a plurality of points, comprising:

obtaining coordinate data and normal vector data associated with each point of a starting set of points, where the starting set comprises at least three non-linear points; ~~and~~

determining a first estimated relationship between the plurality of points based on the coordinate data and the normal vector data associated with the starting set of points;

determining a target point corresponding to a point having a maximum estimated error within the first estimated relationship between the plurality of points; and

obtaining coordinate data and normal vector data for the target point if the maximum estimated error is greater than a predetermined error limit.

2. (canceled)

3. (original) The method of claim 1, where the starting set further comprises points defining a boundary of the plurality of points.

4. (original) The method of claim 1, where determining the first estimated relationship between the plurality of points further comprises interpolating between the starting set of points according to a predetermined estimator that incorporates the obtained coordinate data and the obtained normal vector data and generates estimated coordinate data and estimated normal vector data.

5. (original) The method of claim 4, where the predetermined estimator comprises a function for representing a multi-dimensional relationship.

6. (original) The method of claim 4, where the predetermined estimator comprises a cubic spline function.

7. (currently amended) The method of claim 1~~2~~, where determining the target point further comprises comparing the first estimated relationship between the plurality of points to a reference relationship between the plurality of points to determine a difference defining an error relationship between the plurality of points, where the reference relationship between the plurality of points comprises a plurality of points having reference coordinate data and reference normal vector data, where the error relationship between the plurality of points comprises a plurality of points having coordinate data error and normal vector data error, and where the maximum estimated error corresponds to the maximum absolute value of the coordinate data error or the normal vector data error.

8. (original) The method of claim 7, where the reference relationship between the plurality of points comprises a plurality of points having predetermined values.

9. (original) The method of claim 8, where the predetermined values define the relationship between the plurality of points according to predetermined standards.

10. (original) The method of claim 8, where the predetermined values are zero.

11. (currently amended) The method of claim 1~~2~~, where the predetermined error limit corresponds to a predetermined level of accuracy.

12. (currently amended) The method of claim 1~~2~~, further comprising:

obtaining coordinate data and normal vector data for each point of a second set of points if the maximum estimated error is greater than the predetermined error limit; and

determining a second estimated relationship between the plurality of points representative of a subset of the plurality of points based on the second set of coordinate data and the second set of normal vector data.

13. (original) The method of claim 12, where the second set comprises at least the target point and two of the three points of the starting set.

14. (original) The method of claim 12, further comprising:

determining a new target point corresponding to a new maximum estimated error within the second estimated relationship between the plurality of points; and

obtaining coordinate data and normal vector data for the new target point if the new maximum estimated error is greater than the predetermined error limit.

15. (original) The method of claim 1, further comprising removing data associated with the first estimated relationship between the plurality of points based on the normal vector data.

16. (currently amended) A method for estimating a relationship between a plurality of points, comprising:

generating a first estimated relationship between the plurality of points based on measured coordinate data and normal vector data, the measured coordinate data comprising a measured value of a vector associated with a point corresponding to a given one of the plurality of points, the normal vector data representative of a local rate of change with respect to the vector associated with the given one of the plurality of points, the first estimated relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; and

automatically determining whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria comprising error limitations.

17. (original) The method of claim 16, where generating the first estimated relationship between the plurality of points further comprises:

generating coordinate data error and normal vector data error respectively corresponding to the measured coordinate data and the normal vector data; and

generating the first estimated relationship between the plurality of points according to a predetermined estimation function and based on the coordinate data error and the normal vector data error.

18. (currently amended) The method of claim 16, where the predetermined measurement criteria comprise criteria selected from the group consisting of physical limitations~~, error limitations,~~ and rule-based criteria.

19. (currently amended) A method of estimating a relationship between a plurality of points, comprising:

removing data from a plurality of coordinate data and normal vector data associated with measured points defining a starting set associated with the plurality of points based on estimated normal vector data associated with the measured points, thereby defining a revised starting set, wherein the data is removed based on error limitations; and

generating a first estimated relationship between the plurality of points based on the coordinate data and the normal vector data of the revised starting set, the coordinate data comprising a measured value of a vector associated with a point corresponding to a given one of the plurality of points, the normal vector data comprising a the local rate of change associated with the vector of the given one of the plurality of points, the first estimated relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points.

20. (cancelled)

21. (currently amended) A computer readable medium for estimating a systematic relationship between a plurality of points, comprising:

an estimation module having a predetermined estimation function operative to generate a first estimated systematic relationship between the plurality of points based on coordinate data and normal vector data, the coordinate data comprising a measured value of a vector corresponding to a given one of the plurality of points, the , the first estimated systematic relationship between the plurality of points derived from estimated normal vector data corresponding to at least a portion of the plurality of points; and

an adaptive sampling module operative to automatically determine whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria comprising error limitations.

22. (original) The computer-readable medium of claim 21, where the predetermined estimation function comprises a function for representing a multi-dimensional relationship.

23. (currently amended) The computer-readable medium of claim 21, where the predetermined measurement criteria comprise criteria selected from the group consisting of physical limitations~~, error limitations,~~ and rule-based criteria.

24. (currently amended) A system for estimating a systematic relationship between a plurality of points, comprising:

an estimator having an estimation function operable for determining a first estimated systematic relationship between the plurality of points, the first estimated systematic relationship between the plurality of points having coordinate data and normal vector data determined from a starting set of measured points associated with the plurality of points;

wherein the coordinate data comprise a value of a vector associated with the plurality of points;~~ and~~

wherein the normal vector data comprise a value of a local rate of change of the vector associated with the plurality of points; and

wherein the estimator further comprises reference coordinate data and reference normal vector data respectively corresponding to a reference systematic relationship between the plurality of points, the reference systematic relationship between the plurality of points representing a known systematic relationship between the plurality of points, the estimator further comprising coordinate data error and normal vector data error, the coordinate data error representing a difference between the coordinate data and the reference coordinate data and the normal vector data error representing a difference between the normal vector data and the reference normal vector data, wherein the first

estimated systematic relationship between the plurality of points is determined based on the coordinate data error and normal vector data error.

25. (cancelled)

26. (original) The system of claim 24, further comprising an adaptive sampling mechanism having predetermined measurement criteria, wherein the adaptive sampling mechanism is operative to generate a measurement decision based on an evaluation of the coordinate data and the normal vector data with respect to the predetermined measurement criteria.

27. (original) The system of claim 24, wherein the predetermined measurement criteria comprise criteria selected from the group consisting of physical limitations, error limitations, and rule-based criteria.

28. (original) The system of claim 24, wherein the estimation function comprises a function for representing a multi-dimensional relationship.

29. (original) The system of claim 26, where the estimation function comprises a cubic spline function.

30. (original) A system for estimating a systematic relationship between a plurality of points, comprising:

an estimator comprising a first program operable for receiving coordinate data and normal vector data associated with each of a starting set associated with the plurality of points, wherein the starting set comprises at least three non-linear points, the estimator further comprising a first estimated systematic relationship between the plurality of points and a predetermined estimation function, the first estimated systematic relationship between the plurality of points comprising estimated coordinate data and estimated normal vector data representative of an estimate of the systematic relationship between

the plurality of points and generated by the predetermined estimation function based on the coordinate data and the normal vector data; and

an adaptive sampling mechanism operative on a systematic relationship error representative of a difference between the first estimated systematic relationship and a reference systematic relationship, wherein the reference systematic relationship comprises reference coordinate data and reference normal vector data each having desired values associated with the plurality of points, wherein the systematic relationship error comprises a plurality of points corresponding to the reference systematic relationship and having coordinate data error and normal vector data error, the adaptive sampling mechanism further operative to generate a target point and further comprising a predetermined error limit, the target point corresponding to a point having a maximum estimated error within the systematic relationship error and the predetermined error limit comprising a value determinative of an acceptability of the systematic relationship error.

31. (cancelled)

REMARKS

This Response is responsive to the Office Action mailed by the Office on July 2, 2004. Claims 1-31 were pending in the application. Claim 30 is allowed. Claims 1-6, 11, 15-24, 26-29, and 31 stand rejected. Claims 7-10, 12-14, and 25 are objected to but would be allowable if rewritten in independent form, incorporating the limitations of the base claim and any intervening claims.

Claims 1, 3-6, and 20 stand rejected under 35 U.S.C. § 102(e) as allegedly anticipated by U.S. Patent No. 6,373,491 to Sasaki (hereinafter "Sasaki"). Claims 2, 11, 15-19, 21-24, 26-29, and 31 stand rejected under 35 U.S.C. § 103(a) as allegedly unpatentable over Sasaki in further view of U.S. Patent No. 6,556,198 to Nishikawa (hereinafter "Nishikawa").

Applicants have amended claims 1, 7, 11, 12, 16-19, and 21-24 and cancelled claims 2, 20, 25, and 31. Applicant has also amended the specification to correct several typographical errors. No new matter has been added by these amendments and support for the amendments may be found in the specification and claims as originally filed. After these amendments, claims 1, 3-19, 21-24, and 26-30 are pending in the application.

Applicants respectfully traverse the rejections. Reconsideration of this application is respectfully requested.

I. Claims 1, 3-6, and 20

Claims 1, 3-6, and 20 stand rejected under 35 U.S.C. § 102(b) as unpatentable over Sasaki. Applicant has amended claims 1 and 20. Claim 1, as amended, incorporates the elements of claim 2. Claim 2 has been cancelled. Before these amendments, claim 2 depended from claim 1. The rejection of claim 1 is rendered moot by these amendments. The rejection of claim 2 is now applicable to claim 1, as amended, and is addressed in section II below.

Claims 3-6 depend from claim 1. Thus, the rejection of claims 3-6 under 35 U.S.C. § 102(b) is rendered moot as well.

Claim 20 has been cancelled. Thus, the rejection of claim 20 has been rendered moot.

Applicant respectfully request that the Examiner withdraw the rejection of claims 1, 3-6, and 20 under 35 U.S.C. § 102(e).

II. Claims 2, 11, 15-19, 21-24, 26-29, and 31

Claims 2, 11, 15-19, 21-24, 26-29, and 31 stand rejected under 35 U.S.C. § 103(a) as unpatentable over Sasaki in further view of Nishikawa. To establish a prima facie case of obviousness, there must be some suggestions or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Further, the prior art reference (or references when combined) must teach or suggest all the claim limitations. See, MPEP 2142. Applicants respectfully assert that Sasaki in further view of Nishikawa does not support a prima facie case of obviousness, as is required by MPEP §2142.

Claim 2 has been cancelled. However, claim 2 depended from claim 1, and claim 1 has been amended to incorporate the elements of claim 2. In claim 1, as amended, Applicants claim, "determining a target point corresponding to a point having a <u>maximum estimated error</u> within the first estimated relationship between the plurality of points." Neither Sasaki nor Nishikawa teaches or suggests, "determining a target point corresponding to a point having a maximum estimated error within the first estimated relationship between the plurality of points."

In the office action, the "maximum estimated error" is equated to the "farthest point" described in Nishikawa. Office Action, page 4. But Nishikawa is not describing a maximum estimated error. Nishikawa describes a process of generating a polyhedron enveloping a sequence of points. Abstract. The process for generating the polyhedron that is cited in the Office Action comprises forming an octahedron utilizing points in the polyhedron, eliminating the points that are contained within the planes of the octahedron, selecting an existing point of the polyhedron that is outside of the octahedron and farthest from a plane of the octahedron, building a tetrahedron that comprises the plane of the octahedron and the farthest point, and eliminating the points of the polyhedron that lie within the tetrahedron. Column 9, lines 1-34. The process of building the tetrahedron and eliminating points within the tetrahedron is repeated for each plane of the octahedron. Column 9, lines 34-36. Eliminating the points within the octahedron and corresponding

tetrahedrons increases the speed of generating the polyhedron. Col. 9, lines 53-56. The farthest point is not a "maximum estimated error."

Thus, neither Sasaki nor Nishikawa teaches or suggests, "determining a target point corresponding to a point having a maximum estimated error within the first estimated relationship between the plurality of points." Accordingly, claim 1, as amended, is patentable over Sasaki in view of Nishikawa. Applicants respectfully request that the Examiner withdraw the rejection of claim 1 under 35 U.S.C. § 103(a).

Claims 3-6, 11, 13, and 15 depend from claim 1 and are allowable for at least the same reasons. Applicants respectfully request that the Examiner withdraw the rejection of claims 3-6, 11, 13, and 15.

In claim 16, as amended, Applicant claim a method comprising "automatically determining whether further measurements are required based on the estimated normal vector data in combination with <u>predetermined measurement criteria comprising error limitations</u>." Neither Sasaki nor Nishikawa teaches or suggests, "automatically determining whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria comprising error limitations." Accordingly, claim 16, as amended, is patentable over Sasaki in view of Nishikawa. Applicants respectfully request that the Examiner withdraw the rejection of claim 16.

Claims 17 and 18 depend from claim 16 and are allowable for at least the same reasons. Applicants respectfully request that the Examiner withdraw the rejection of claims 17 and 18.

In claim 19, as amended, Applicants claim a method comprising "removing data from a plurality of coordinate data and normal vector... <u>wherein the data is removed based on error limitations</u>." Neither Sasaki nor Nishikawa teaches or suggests, "removing data from a plurality of coordinate data and normal vector... wherein the data is removed based on error limitations." Accordingly, claim 19, as amended, is patentable over Sasaki in view of Nishikawa. Applicants respectfully request that the Examiner withdraw the rejection of claim 19.

In claim 21, as amended, Applicants claim a computer-readable medium comprising "an adaptive sampling module operative to automatically determine whether

further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria comprising error limitations." Neither Sasaki nor Nishikawa teaches or suggests, "an adaptive sampling module operative to automatically determine whether further measurements are required based on the estimated normal vector data in combination with predetermined measurement criteria comprising error limitations." Accordingly, claim 21, as amended, is patentable over Sasaki in view of Nishikawa. Applicants respectfully request that the Examiner withdraw the rejection of claim 21.

Claims 22 and 23 depend from claim 21 and are allowable for at least the same reasons. Applicants respectfully request that the Examiner withdraw the rejection of claims 22 and 23.

Claim 25 was objected to in the Office Action but would be allowable if rewritten in independent form, incorporating all of the limitations of the base claim. Claim 25 depended from claim 24. Applicants have amended claim 24 to incorporate the elements of claim 25 and cancelled claim 25. Accordingly, claim 24, as amended, is allowable. Applicants respectfully request that the Examiner withdraw the rejection of claim 24.

Claims 26-29 depend from claim 24 and are allowable for at least the same reasons. Applicants respectfully request that the Examiner withdraw the rejection of claims 26-29.

Applicants have cancelled claim 31. Accordingly, the rejection of claim 31 is moot.

III. Claim 30

Applicants appreciate the allowance of claim 30.

IV. Claims 7-10, 12, 14, and 25

Claims 7-10, 12-14, and 25 are objected to but would be allowable if rewritten in independent form, incorporating the limitations of the base claim and any intervening claims. Claims 7-10, 12, and 14 depend from claim 1. As discussed in section II above, claim 1, as amended, is allowable. Claims 7-10, 12, and 14 are allowable for at least the

reasons discussed in relation to claim 1. Applicants respectfully request that the Examiner withdraw the objections to claims 7-10, 12, and 14.

Claim 25 has been cancelled. Accordingly, the rejection of claim 25 is moot and Applicants respectfully request that the Examiner withdraw the objection to claim 25.

CONCLUSION

Applicant respectfully asserts that in view of the amendments and remarks above, all pending claims are allowable and Applicant respectfully requests the allowance of all claims.

Should the Examiner have any comments, questions, or suggestions of a nature necessary to expedite the prosecution of the application, or to place the case in condition for allowance, the Examiner is courteously requested to telephone the undersigned at the number listed below.

Respectfully submitted,

Date: 1/14/2009

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